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NONPOINT-SOURCE POLLUTION IN SURFACE WATERS: ASSOCIATED PROBLEMS AND INVESTIGATIVE TECHNIQUES

National Environmental Research Center
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NONPOINT-SOURCE POLLUTION IN SURFACE WATERS:

Associated Problems and Investigative Techniques

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Water and Land Monitoring Branch
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National Environmental Research Center
Las Vegas, Nevada

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NATIONAL ENVIRONMENTAL RESEARCH CENTER
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Effective June 29, 1975, the National Environmental Research Center-Las Vegas (NERC-LV) was designated the Environmental Monitoring and Support Laboratory-Las Vegas (EMSL-LV). This Laboratory is one of three Environmental Monitoring and Support Laboratories of the Office of Monitoring and Technical Support in the U.S. Environmental Protection Agency's Office of Research and Development.

ABSTRACT

Contaminants entering waterways from diffuse or non-distinct points are termed nonpoint-source pollutants. Principal categories of nonpoint-source pollutants in surface waters include sediments, minerals and acids, pesticides, nutrients, organic matter, heat, microorganisms and radioactive materials. Nonpoint-source pollutants are generated primarily by such activities as agriculture, silviculture, mining, construction and hydrographic modifications. In terms of volume alone, sediment is the pollutant of greatest significance, and agricultural cropland is the chief contributor. Various models are available for predicting rates and effects of nonpoint pollutants in surface water. Capabilities for predicting sedimentation rates, thermal pollution and mine drainage are fairly sophisticated, but methods for predicting pollution resulting from pesticides, nutrients, heavy metals, biological contaminants and organic wastes are not well refined. Techniques for monitoring nonpoint-source pollutants include manual field sample collection, automated samplers, automatic contact sensors, and to an extent, remote sensing devices. Parameters which can be automatically monitored *in situ* with contact sensors include turbidity, temperature, certain specific ions, specific conductance, pH and dissolved oxygen. Most other parameters must be measured using laboratory analytical procedures. Aerial reconnaissance can be used in a cost-effective manner to assess the impact of agriculture, construction, mining and silviculture activity on waterways, but quantitative water quality data cannot be reliably produced with remote sensing techniques.

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SUMMARY

Nonpoint-source pollutants are those water-degrading substances which enter waterways from diffuse or non-distinct points in such a manner that treatment at the source is impossible or impractical. The major categories of nonpoint-source pollutants include sediments, minerals and acids, pesticides, nutrients, organic matter, heat, microorganisms and radioactive wastes. Nonpoint-source pollutants are generated primarily by such activities as agriculture, silviculture, mining, construction and hydrographic modification. Each of these activities releases numerous water-degrading substances to surface water, but in terms of volume alone, sediment is the pollutant of greatest significance, and agricultural cropland is the chief contributor.

Various models for predicting input and output of pollutants are available for use by planners and engineers in designing control and monitoring programs for nonpoint pollutants. These predictive tools vary tremendously in levels of sophistication and utility. Methods for predicting sedimentation rates, thermal pollution and mine drainage are fairly well developed, while predictive capabilities for pesticides, nutrients, heavy metals, biological pollutants and organic wastes are not well refined.

Water monitoring programs to be instituted by the States are required by Federal legislation to assess trends in water quality, to evaluate the effectiveness of pollution control and abatement actions and to determine the need for reduction of such programs. Automated monitoring of certain critical parameters is possible with contact sensors. The state-of-the-art of automated sampling and continuous data recording permits the development of a monitoring system for selected parameters that will maintain its calibration, accuracy and reproducibility for approximately 1 month unattended. The system can also be designed to permit the telemetering of data to a central point at predetermined finite intervals. Parameters which can be monitored automatically with a minimum of maintenance include turbidity, temperature, certain specific ions, specific conductance, pH, and dissolved oxygen. Sensors are being developed to detect oil and grease in water, but identification and quantification of these substances require laboratory analyses.

Manual field sampling and/or automatic composite sampling are required to provide samples for analysis of numerous parameters which are not easily measured *in situ* with contact sensors. Included in this category of parameters which are usually measured in the laboratory are nutrients, pesticides, heavy metals, many specific ions, suspended and dissolved solids, acidity, alkalinity, chemical oxygen demand and total organic carbon.

Aerial reconnaissance can be used in a cost-effective manner to assess the impact of agriculture, construction, mining and silviculture operations on waterways. Aerial photography is useful to aid in determining whether control measures have been implemented within a given study basin. Remote sensors are currently being developed which may provide information on relative sediment and salinity concentrations in a given waterway, thus focusing attention upon potential problem areas.

INTRODUCTION

Historically, the major efforts in this country to combat water pollution have been directed toward the control and abatement of polluting substances originating from discrete point sources such as municipal sewage treatment plant effluents and industrial waste discharges. Recently, the need for programs to control pollutants arising from diffuse or nonpoint sources has been emphasized in an attempt to meet the objectives of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), which call for the complete elimination of pollution discharges to the Nation's waters by 1985.

The need for an assessment of nonpoint pollution sources and measures for the control of such pollutants is recognized in Section 204(e), PL 92-500, which requires the Administrator of the U.S. Environmental Protection Agency (EPA) to issue information including: (1) guidelines for identifying and evaluating the nature and extent of nonpoint sources of pollutants, and (2) processes, procedures, and methods to control pollution resulting from (a) agricultural and silvicultural activities, (b) mining activities, (c) construction, (d) subsurface disposal of pollutants, (e) salt water intrusion, and (f) hydrographic modification. Pursuant to this legislative mandate, EPA's Office of Air and Water Programs issued several reports addressing each of these nonpoint-source pollution categories. For an in-depth treatment of problems associated with each category and possible control measures, the reader is referred to the appropriate report in the series cited in the References section of this report (EPA, 1973 a-h).

The current national goal of zero discharge by 1985, including abatement of nonpoint pollution, has placed an urgent demand on technological capabilities for assessing progress toward this goal. This necessitates the implementation of effective monitoring programs, the refinement of techniques and the development and utilization of sophisticated sensing instruments, including remote sensors, whenever possible. It is the intent of this report to present a synopsis of the major categories and sources of nonpoint pollution affecting the Nation's surface waters, the effects of such pollution, and state-of-the-art information on existing capabilities for predicting, detecting and measuring such pollutants in surface waters. No attempt is made to address groundwater pollution problems, control measures or monitoring techniques.

NATURE AND ORIGIN OF NONPOINT-SOURCE POLLUTION

Nonpoint pollutants are those water-degrading substances which enter waterways from diffuse or non-distinct sources. Nonpoint-source pollutants are generally not confined to discrete conveyances, thus treatment at the source is usually impossible. The nature of nonpoint-source pollutants is generally similar to that of point sources, but the mode of transport to waterways may differ.

CATEGORIES OF NONPOINT-SOURCE POLLUTANTS

Sediments

The principal polluting agent generated by nonpoint sources as a group is sediment. The greatest loading of sediment is attributed to cropland runoff which may account for over 50 percent of the loading in fluvial systems (EPA, 1973 a). Other farming operations, silviculture, construction and mining activities also contribute substantial sediment loads to streams and lakes. While sediments themselves act as primary pollutants, they also transport a wide range of attached or sorbed materials which may act as primary contaminants or as carriers of other pollutants.

Minerals and Acids

Another major class of nonpoint-source pollutants includes various minerals released by man-induced exposure of bedrock and natural mineral phases to weathering, thus enhancing the mobility of the product. These processes generate acid mine drainage and enhance salinity and toxic metal concentrations in aquatic systems.

Pesticides

Chemical pesticides which are released directly into the environment during utilization contribute substantially to nonpoint-source pollution problems. Pesticides include insecticides, herbicides, mitecides, nematocides, rodenticides, fungicides, plant growth regulators, and desiccants, all of which are used extensively in agriculture and silviculture. Many pesticides used are resistant to degradation, and their metabolites or degradation products may persist or accumulate in aquatic ecosystems impacting the entire food web, up to and including man.

Nutrients

Nutrient elements, particularly nitrogen and phosphorus, also constitute a class of nonpoint-source pollutants. Phosphorus is of special concern because of its role in eutrophication. Nitrogen is also involved in the eutrophication process and nitrate and ammonia nitrogen species are toxic to animal life.

Organic Substances

Natural and synthetic organic waste materials are generated in part by nonpoint sources. Most of the natural organic materials (e.g., livestock wastes, forest litter, crop debris) are readily degradable and upon reaching a water body may create a heavy oxygen demand on the system. Many synthetic organic products are less easily degraded (e.g., petroleum products) and may cause serious problems in aquatic systems. Such organic products as polychlorinated biphenyl compounds (PCB's) which are very resistant to degradation have in recent years become ubiquitous components of the environment.

Heat

Heat can be considered a class of pollution derived in part from nonpoint sources as alteration of the thermal regimens of water bodies is frequently brought about by modification of channel configurations and changes in the stream bank and watershed vegetation.

Microorganisms

Microbial contamination is an additional distinct class of nonpoint pollution. Pathogenic microbial organisms originating from livestock wastes may be transmitted to surface waters. The extent of this problem is unknown, but it remains an area of concern.

Radioactive Materials

Radioactive pollutants constitute a final class of nonpoint-source pollutants. Radioactive pollutants are generated as by-products of certain mining operations and fossil fuel production and combustion. The radioactive mineral mining industry is also a source of nonpoint radiation. Extensive continuous monitoring reveals that, except in a few isolated cases, levels of radio-activity in aquatic systems are below levels judged to be hazardous.

SOURCES OF NONPOINT POLLUTANTS

The principal human activities which result in nonpoint-source pollution of surface waters are agriculture, silviculture, mining, construction activity and hydrographic modification. Potentially, each of these activities could release a myriad of pollutants as discussed below.

Agriculture

Agriculture has long contributed a number of pollutants to the aquatic environment, and recently many new synthetic materials have been developed for use in agriculture, expanding the inventory of possible pollutants.

Nonpoint sources of agricultural pollutants fall into two broad classes: those resulting from the cultivation of food or forage crops, and animal wastes. In the former class, sediment is probably the chief pollutant in terms of impaired utility of water bodies, and its mode of origin, i.e., erosion from crop-land, constitutes a major threat to the stability of the agri-cultural economy. Approximately 3.6 billion metric tons of sediment per year are eroded from cropland in the United States and it is believed that one half of this sediment finds its way into the Nation's lakes and streams (Holeman, 1968). While

sediment transport in streams is a natural process, the rate of transport is very sensitive to the vegetational and climatic status of the drainage area. The gross alteration of vegetational patterns usually enhances surface instability and, therefore, increases erodibility. Agricultural methods have been altered to decrease this problem in some areas, but a concerted nationwide effort will be required to control this source of pollution.

Relatively low costs of commercial fertilizers and the necessity for higher economic yields have in recent years resulted in increased usage of commercial fertilizer in agricultural operations. In 1972 about 37 million metric tons of commercial fertilizers were consumed in the United States, about 75 percent of which was used in agricultural activities (EPA, 1973 a). The national average composition for the nutrient elements is about 20 percent nitrogen, 5.2 percent phosphorus and 8.8 percent potassium (EPA, 1973 a). Regional soil conditions dictate that the composition used in any given locality may deviate substantially from the national average. Rates of nutrient losses from cropland are a function of precipitation or other applied water, temperature, soil type, crop grown and cultivation methods used. It is not known what percentage of the total quantities of nutrients applied via commercial fertilizers actually reaches waterways, but data indicate that runoff from rural watershed represents a significant fraction of phosphorus and nitrogen appearing in our surface waters (Verduin, 1970; Goldberg, 1970).

Total quantities of pesticides used in domestic agriculture have increased steadily over the years. Pimentel (1971) estimated that of the 453,600 metric tons (1 billion pounds) of pesticides applied domestically during 1970, about 70 percent was used on farms. Agricultural pesticides may enter the aquatic environment directly or indirectly. The direct route involves application to waters for control of specific aquatic organisms (e.g., aquatic weeds, algae, insect pests, etc.) and drift from aerial application to adjacent farmlands. Primary indirect routes include overland runoff, volatilization and subsequent atmospheric washout, and discharge of wastewater contaminated by cleaning sprayers and containers. Few data are available to relate quantities of pesticide applications on farmland to residue levels in water bodies, but overland runoff is considered to be a major source of pesticides in the Nation's waterways.

Irrigation poses a special threat to streams, particularly in the Western States which contain about 90 percent of the irrigated land in the United States. Irrigation agriculture accounts for approximately 85 percent of the total national water consumption, and as much as 65 percent of the water applied during irrigation is lost to the atmosphere through evaporation and transpiration (Jenke, 1974). Water that is returned to the surface or subsurface systems is termed irrigation return flow. The concentration of substances in applied irrigation waters is increased by evaporation and transpiration, and return flows also pick up natural salts from the soil. Consequently, irrigation not only diminishes the quantity of water in a system through consumptive uses, but degrades the quality as well by returning waters with high concentrations of salt and other dissolved and suspended materials to the system. Although increases in salinity concentrations in hydrologic systems which receive irrigation return flows pose the major problem in waterways in irrigated areas of the country, degradation of water quality from other causes is also of concern. Surface runoff water from irrigated lands may contain high levels of pesticides, fertilizers, organic debris, sediments, heavy metals, bacteria (including pathogens), and other pollutants derived from the land and transported to lakes and streams.

The volume of animal wastes produced in the United States is about 10 times that produced by the human population (EPA, 1973 a). Animal wastes constitute a major source of organic loading to waterways, with the primary impact coming from confined animal populations.

The high concentration of wastewater in a relatively small area precludes rapid biological degradation, and the pollution potential is increased greatly over non-confined animals. Some animal waste generated in pastures, however, may reach waterways, since livestock tend to congregate in watering, resting and supplementary feeding areas, thus concentrating the wastes. Livestock wastes, in addition to increasing the nutrient and organic load in waterways, are also a source of pathogens.

Silviculture

Silviculture, the commercial management of trees, has a high pollution-generating potential. The principal pollutant associated with silvicultural activities is sediment. Since operations of harvesting alter or disrupt surface cover, surface soil is subject to erosion and subsequent transport into adjacent streams. Surface runoff also carries synthesized compounds such as pesticides and fire retardant chemicals used in forest management. Also of significance is the alteration of the thermal budget resulting from changes in solar penetration in runoff areas and along stream channels.

Surface disruption during harvesting occurs during access road construction, as well as during the actual timber removal operation in harvesting and yarding/staging areas. Post-harvesting surface disruption results from increased surface exposure to raindrop impact, loss of the stabilizing effect of live root networks, and decreased or eliminated input of forest debris which increases the erodibility of the forest soils.

Surface disruption is not an exclusively man-induced factor in forested areas. It can be promoted by windstorms, drought, extremely heavy downpours, and rapid snow melt. Fire, disease, and insect infestation also contribute to surface changes which lead to increased erosion. Alteration of surface vegetation increases solar input to surface soils and waterways, leading to higher temperatures of water bodies.

A wide range of pesticides is utilized in forest management including insecticides, fungicides, herbicides, and rodenticides. Since these materials are clearly not a part of the natural setting, their role in water pollution is pronounced. Careless aerial application of pesticides results in direct input into lakes and streams.

Aerial application of fertilizers and fire retardants to forested lands may result in direct loading to streams. Although not applied as a fertilizer, fire retardants usually contain either phosphates or ammonia, thus having much the same effect as fertilizers in waterways.

Mining

Mining activities, present and past, have created severe water pollution problems in lakes and streams. The pollutants resulting from mining are both an expression of the mining procedure used and the types of material being extracted. Each mining method has its own selected problems of pollution potential and must be analyzed accordingly. Pollutants generated are often very much dependent on the ore mineral assemblage.

Unlike other nonpoint sources, the primary pollutant from mining activity is not sediment, but a water quality degrading solution of sulfuric acid, iron salts, and other salts. Generally referred to as acid mine drainage, it results from the oxidation of iron disulfides, pyrite, and marcasite, which are commonly found within a wide range of material. Coal mines have been a primary offender, but acid mine drainage is also a problem in some hard-rock mining areas.

Sediment can be a major pollutant from mining operations, especially in strip mining areas which may involve large tracts of land. This is particularly true in some coal and iron ore mining operations. Tailings, the spent residues of ore extraction, are often very fine grained and, therefore, are easily mobilized by runoff.

Mining operations directed at recovering some specific compound or metal may induce the entry of that same material into the aquatic environment as a pollutant. Leakage of this sort may be very dangerous if the escaping material is toxic at low concentrations or undergoes enhancement in the biological or geochemical chain to toxic levels. Leachates from tailings and spills can add a variety of materials as well. These materials include trace elements in ore bodies which may not be extracted in the milling process, but can be lost to streams as a pollutant in concentrations that may be toxic to the biota of the stream.

Of special concern is the composition of runoff and leachate from mining activities associated with extraction and recovery of radioactive ores. Tailings from uranium operations in the Colorado River Basin and South Dakota have been subject to extensive study. Although radioactivity in these areas is not above permissible levels, long-term effects are not clearly known. Radioactive nuclides, as trace elements in coals, have been observed in significant concentrations in the Allegheny River (Caldwell, et al., 1970). Coal deposits in the West also contain uranium, but less information is available on their effect on water quality. Clearly, radioactive nuclides may be a significant pollutant from mining of carbonaceous materials such as coal and oil shale.

Salinity increases in streams in the Western United States have been related in the past to mining operations. It is estimated that about 20 tons per day of dissolved solids enter streams of the San Juan Mountains which drain to the Colorado River (Blackman, et al., 1973).

Other pollutants which may result from mining operations are phosphates and nitrates used as fertilizers to promote groundcover on various types of debris created during mining operations. Pesticides of various sorts may also be leached from disturbed soils in the mining area. Microbial contamination associated with wastewater generated at the milling and mining sites may also be of significance.

Construction

Construction of facilities such as highways, dams, housing developments and other energy consuming or producing sites contribute nonpoint pollutants to waterways. The principal pollutants generated by these activities are sediments and storm water. Other pollutants are sorbed to sediment or mobilized by the same processes which entrain detrital debris. These include organic matter, fertilizers, pesticides, and bacteria which were reasonably well stabilized in the soil. Additionally, potential pollutants are produced by the full range of chemicals and products of waste-generating processes involved in construction activities.

Hydrographic Modification

Hydrographic modification includes procedures that change the movement, flow, or circulation of any navigable waters or groundwaters. These include changes caused by the construction of dams, levees, channels or flow diversion facilities. Interpreted in the broadest sense, this could include almost all terrestrial modifications, since they all alter the patterns and composition of the runoff that eventually enters navigable streams. However, this overview is restricted to effects resulting from direct modification of navigable streams or channels of high order ephemeral streams.

Channelization involves modifying the streamway in an effort to improve flow in the channel, thus resulting in substantial alterations of habitats; the creation of impoundments on streams causes significant changes by creating a lake where there was once flowing water; and dredging operations, gravel mining and the disposal of generated waste substantially alter characteristics of the waterways. Generally, these activities in addition to altering the physical nature of the channel, induce changes in the thermal patterns of the waterway.

Channelization -

Channelization has been promoted and practiced by a number of government and private agencies. The principal Federal agencies involved in this activity are the Soil Conservation Service, U.S. Army Corps of Engineers, and the Bureau of Reclamation. Channelization is usually directed at flood control and improvement of drainage characteristics.

Sediment is "the most ubiquitous of all pollutants associated with channelization" (EPA, 1973 c). During construction activities in channelization, sediment is a very pronounced pollutant and frequently remains a serious problem after alterations have been stabilized by vegetation.

Alteration of stream temperatures, subsequent to channelization may induce a change in the aquatic communities. Components of the existing communities which are susceptible to wide fluctuations in temperature and dissolved oxygen levels may be unable to adapt to the new thermal regimen, and eventually may be replaced by species with wider tolerance ranges. Although all life stages of the biota may be subjected to stress conditions by these changes, disruptions to reproductive patterns seem to have the greatest impact upon community structure.

Increased velocity of water in channelized streams has a tendency to extend the downstream distribution of sediments and other pollutants introduced into the stream. The velocity drop associated with the downstream non-channelized reaches may result in deposition and upstream migration of sediments into the channelized segment, clogging the channels and defeating the purpose of channelization.

Impoundments -

Manmade impoundments or reservoirs are lakes formed by the damming of fluvial systems. Impoundments have many features in common with natural lakes. However, the former are distinguished by two general characteristics: (1) rates of discharge from many reservoirs are subject to manipulation which may result in a greater fluctuation in water level and volume than normally occur in natural lakes; and (2) in direct contrast to natural lakes, outlets of impoundments often discharge water from a location other than the surface. These two factors not only cause changes in the quality of the impounded waters, but also in the water downstream.

Periodic drawdown of an impoundment is an example of manipulation. This process may expose large expanses of the littoral zone to the atmosphere. Such exposure reduces the volume of the hypolimnion and the acreage available to sustain rooted aquatic plants in addition to destroying biotic shelters and compacting sediments. The organisms themselves may suffer from exposure to the atmosphere. Nevertheless, drawdown and eventual reflooding can be effective lake management tools to provide suitable habitats for desirable organisms and to influence nutrient availability.

The practice of discharging hypolimnetic waters, as is done in some reservoirs, has a profound effect upon downstream reaches. The release of hypolimnetic waters may create an environment suitable for a cold water fishery in a stream which once supported only warm water species. Primary productivity of nutrient-rich hypolimnetic waters may also be increased by release to a flowing system and subsequent exposure to increased light intensity. Once the nutrient-rich waters are discharged to a flowing system, the response of the biota may be immediate, resulting in greatly increased photosynthetic activity.

The creation of impoundments in a once fluvial setting requires an adjustment by the biota in response to the physical and chemical changes associated with the new lentic environment. The extent of the biological change is dependent upon the magnitude of change in hydraulic character, and other physical and chemical alterations. Biological communities requiring flowing waters will obviously give way to lentic species, while terrestrial communities will be replaced by aquatic plant and animal associations. Impounded waters will, to an extent, reflect the chemical nature of the inundated basin, thereby further influencing the composition of the biota. Since impoundments are frequently formed by flooding fertile bottom lands, the impounded water may be rich in nutrients and other dissolved and suspended materials. Also, depending upon the nature of the landscape, minerals may be released to the water from rock formations and soils. Physical changes involving temperature regimens, sedimentation rates and turbidity also occur as a result of impounding flowing waters.

Mining Gravel From Streams -

The mining of gravel and sand from stream channels cannot be easily classified as either mining or hydrographic modification. However, the effect of this activity on stream flow seems to be more closely related to hydrographic activities than to the majority of mining activities.

The chief pollutant generated by mining gravel in streams is sediment, resulting in increased stream bedloads and high turbidity. The resettling of fine materials such as clays and silts in the mined pit may retard water infiltration to the groundwater, thereby restricting recharge in the vicinity of the mining site. Bull and Scott (1974) suggest that low water stream bed elevation, and the natural range thereof, may provide a good parameter from which to observe changes resulting from gravel mining operations. They suggest that the physical features of the channel may give meaningful and inexpensive ways of observing changes in the fluvial nature of the system.

Other pollutants are mainly those closely associated with the sediments including nutrient elements, heavy metals, and any synthetic compound sorbed to the surfaces of particles.

Dredging and Dredged Spoil Deposition -

Dredging is usually directed at maintaining navigable channels in rivers and estuaries. The U.S. Army Corps of Engineers has been delegated the task of conducting dredging operations in navigable waters, as well as issuing permits to others who are conducting this type of operation. The Corps was also instructed in the 1970 Amendments to the River and Harbors Act to establish a study of the environmental impact of dredging and the disposal of dredging wastes. From this study, new techniques in both dredging and spoil handling were outlined. In the Federal Water Pollution Control Act Amendments of 1972, the Administrator of the EPA was authorized to compile guidelines for establishing disposal sites.

Mechanical methods of dredging utilize excavation equipment such as draglines, shovels, and trenching equipment, which are located on the banks or on barges. Hydraulic dredging involves disposal via a pipeline.

The greatest pollution hazard to the aquatic environment is not the dredging operation *per se*, but the disturbed sediment and the wide range of sorbed materials. These include the full range of materials generated by man, particularly inorganic nutrients such as phosphorus and nitrates, toxic metals, pesticides, and organic materials such as those occurring in sewage sludge. Dredging increases the exposure of these materials for mobilization, either with suspended sediment or from leaching processes. Secondly, the suspended fraction of the distrubed bottom sediment degrades water quality and detrimentally impacts the biota.

Dredging has other indirect manifestations. Since the channel geometry is usually changed, the velocity, current configuration and sedimentation patterns are altered. Aquatic life forms are often greatly reduced during dredging, and the altered bottom situation is often hostile to repopulation.

Disposal of dredging operation wastes results in increased water turbidity. Waste disposal at terrestrial sites close to the channel may add pollutants, while dewatering either the stream or groundwater.

PREDICTION OF NONPOINT-SOURCE POLLUTION

The ability to predict the rate and nature of pollution loading to a given waterway with accuracy is an essential requirement for planners and engineers concerned with nonpoint-source pollution control. Various methods have been devised for predicting nonpoint-source pollution varying in levels of sophistication from simple rules of thumb to highly complicated computer procedures. A requisite feature of any prediction procedure is a sound data base upon which to operate. Regardless of the level of sophistication of a prediction model, the information generated can be no better than the baseline data which formed the foundation for predicting future events in a given water course. Many prediction models currently available have applications to nonpoint pollutants originating from several sources (e.g., sediment). However, in the following discussion, the reader is briefly introduced to a few of the more common techniques used to predict rates and types of pollutants generated by various activities.

AGRICULTURE

The literature covering agricultural pollution prediction methods is extensive. Since a given drainage basin undergoing modest agricultural activity has a large number of input sites, a prediction methodology will involve input/output evaluation coupled with reaction (chemical and biological) modification during transport and sedimentation (EPA, 1973 a).

Prediction methods exhibit varying degrees of accuracy and completeness. Of the polluting materials from agriculture, sediment is the most prominent and has been most subject to extensive investigation. Table 1 presents a summary of sediment prediction methods which have been field tested and found to be reasonably accurate.

Table 1. SUMMARY OF SEDIMENT PREDICTION METHODS

Prediction Method	PROCESS		
	Erosion	Transport	Deposition
1. Empirical:			
Ellison (1945)	X	-	-
Musgrave (1947)	X	-	-
Universal Soil Loss Equation (Wischmeier and Smith, 1965)	X	-	-
Einstein Bedload Function (Graf, 1971)	-	X	-
Colby Modified Einstein (Graf, 1971)	-	X	-
Toffaleti Total Load Method (Graf, 1971)	-	X	X
Lacey's Silt Theory (Fleming, 1972)	-	X	X
Pemberton Modified Einstein (Pemberton, no date)	-	X	-
Reservoir surveys: ARS SCS Corps of Engineers Bureau of Reclamation U.S. Geological Survey	-	-	X
2. Statistical:			
Flaxman (1972)	-	-	X
Sediment rating-flow duration U.S. Geological Survey Bureau of Reclamation Corps of Engineers	-	-	X
Woolhiser's Deterministic Watershed Model (EPA, 1972)	X	X	X

Table 1 (continued). SUMMARY OF SEDIMENT PREDICTION METHODS

Prediction Method	PROCESS		
	Erosion	Transport	Deposition
3. Simulation:			
ARS Upland Erosion Model (Foster and Meyer, 1972)	X	-	-
ARS USDAHL-73 Watershed Model (Holtan and Lopez, 1973)	X	X	X
ARS "ACTMO" Chemical Transport Model (Onstad, 1973)	-	X	-
Negev's Watershed Model (Negev, 1967)	X	X	X
Stanford IV Model (Crawford and Linsley, 1966)	X	X	X
Hydrocomp Simulation (Crawford, 1970)	X	X	X
Huff Hydrologic Transport Model (Huff, 1972)	-	X	-
Royal Institute (Sweden) Hydrologic Model (Cawood, et al., 1971)	X	X	X
Snyder's Parametric Hydrologic Mcdel (Snyder, 1972)	-	X	X

In predicting and evaluating the nature and extent of pollution from agricultural sources, two modes of investigation may be followed, one of which is the material balance method. Stated simply, the magnitude of pollution is related to the amount of material (i.e., fertilizer, pesticides, etc.) added, less that fraction which is retained by the soil (EPA, 1973 a). Unfortunately, this may be a complex system and the magnitude of some input may be unknown. In the second investigative method, the water monitoring framework is designed so that samples reflect the pollutant component in the selected drainage area. Sampling locations are designed to provide the maximum contrast between land use and geographic features. Such parameters as rainfall, basin geometry discharge characteristics, and chemical and physical reaction rates are weighed to make site selections. Baseline data as acquired and retained by the U.S. Geological Survey (USGS) and EPA provide useful background information. Clearly, the occurrence of concentrations of a given substance over the historical concentration values will strongly suggest loading from some man-related activity.

SILVICULTURE

The generation of sediment in forested areas can be estimated by evaluating several surface factors and erosional modes. The four modes of interest are: (1) surface erosion, (2) gully erosion, (3) mass soil movement, and (4) channel erosion (Flaxman, 1972).

Surface erosion is largely determined by soil, rainfall characteristics, topographical configuration, vegetational cover, and erosional control practices. By examining these factors, the Universal Soil Loss Equation (Wischmeier and Smith, 1965) and the Musgrave Equation (Musgrave, 1947) were developed, Although orginally designed for agricultural areas, these relationships have been found to be applicable in forested areas (Flaxman, 1972).

Contributions to pollution by mass soil movement and channel erosion can be estimated if aerial photography of the areas of interest has been completed over a period of several years. Changes in forest canopy may limit the accuracy of this type of estimation. Gully erosion may also be estimated from aerial photography.

Other pollutants generated during activities associated with silviculture cannot be accurately predicted at the present time. Therefore, the next best course of action would be an input/output evaluation of pollutant expression in waterways from known activities in the drainage basin.

ACID MINE DRAINAGE

Development of models useful in predicting acid mine drainage and leachate from refuse/soil piles has been primarily keyed to pyritic oxidation (Morth, et al., 1972). These types of models are applicable to most coal mines as well as hard-rock mines. Others are keyed to sulfur content of source material (EPA, 1971).

In detecting the manifestation of acid mine drainage in streams, a useful tool is the anion-cation balance outlined in the 13th edition of Standard Methods for Examination of Water and Wastewater (APHA, 1971). This tool gives a straightforward method of handling analytical data from streams suspected to have acid mine drainage loading. Nomograms using this relationship have been developed and presented along with methods for translating raw data to a form where anion-cation balance can be charted (EPA, 1973 a). Hem (1970) also describes several models which use this concept in interpreting water quality data.

IMPOUNDMENTS

Water quality changes caused by reservoirs have been investigated using empirical, physical, and mathematical modeling approaches. Most of these systems require field data to verify or calibrate the predicted changes. Empirical methods are usually reservoir specific, and while usually inexpensive, these methods tend to be inflexible and require extended observational base. Physical models tend to be directed at the hydraulic characteristics of the system. Mathematical models usually attempt to evaluate an aggregation of variables in determining water quality. Basin hydrology and stratification within reservoirs are among the factors examined. Equations are created which attempt to predict water quality as influenced by various factors at various points in space and in time in the system.

DREDGING

Prediction of the extent of water pollution caused by dredging requires an evaluation of the proposed target site. Existing water properties, biota, and historical water pollution of the site area should be examined. Hydraulic alteration can be partly evaluated from physical models. Where dredging will intersect aquifers, the effect of these added waters will also need to be evaluated.

In predicting pollution from spoil disposal in water, the exact characteristics of the solids must be known. The properties of the disposal site such as gradient, current and velocity configuration, and flow volume must be understood. Spoil deposition pollution prediction on terrestrial sites requires that the properties of the spoil be known, as well as the erosional/drainage situation at the disposal site.

NONPOINT-SOURCE MONITORING

The intent of this section is to present a broad overview of monitoring strategy and techniques that can be applied to the identification and assessment of nonpoint-source pollution.

NONPOINT-SOURCE MONITORING STRATEGY

To measure the effectiveness of nonpoint-source control programs, and to assist in identifying and assessing nonpoint sources of pollution, the States can use the primary monitoring program required by PL 92-500, Section 106. The monitoring system will measure the physical, biological and chemical trends within the rivers of each State (Quarles, 1974). The monitoring system is designed to provide information to assess improvements, or the need for improvement, of water quality in each river reach being monitored. If physical, chemical and biological trend data indicate improvement at anticipated rates, such data are to be presented in an annual report format defining the extent to which control actions have been successful, allowing update and redirection of pollution control plans. If, however, water quality shows no improvement or is actually degrading, aerial reconnaissance and intensive surveys of those river reaches may be conducted to determine whether control measures are being used effectively. If it is found that control measures are not effective, additional abatement actions can be instituted. Existing control programs may not be effective because of local conditions or inherent inadequacies; additional research may then be required to correct such inadequacies and make appropriate program modifications.

PRIMARY MONITORING PROGRAM

To assess the effectiveness of nonpoint-source control strategies, it is necessary to evaluate water quality trends. Title 40, Chapter 1, Part 35, Appendix A, CFR (Quarles, 1974) requires the States to establish and maintain a network of primary surface water monitoring stations in which monitoring sites are selected to determine water quality trends. A totally source-oriented network cannot be justified since water quality improvement control is to be achieved in part by implementation of measures to control nonpoint sources of pollution as well as by effluent treatment at point sources.

In establishing the primary network sampling locations, historical water quality data should be used when available. These data provide valuable information for establishing location, frequency, and extent of sampling required to adequately depict water quality trends as well as to provide baseline data on ambient water quality. Stream flow data give added meaning to the sampling information, thus sampling sites established in close proximity to existing stream gauging stations provide maximum information.

WATER DATA ACQUISITION

Two basic questions that must be addressed at this time are: What parameters should be measured, and what method should be employed to monitor them?

> At one time or another, it is conceivable that almost every parameter measurable will be needed on a particular stream. It is impossible, however, to measure every parameter, and consequently, sound judgment must be used in making the final decision. This decision must relate to the particular situation associated with the sampling point. Again, however, it may not be very practical to have a different set of parameters to be measured at every sampling station. Some compromise must be developed with respect to the various situations that occur in a State (EPA, 1973 i).

A few basic parameters common to every sampling point in the primary network give continuity to the data from site to site and from State to State. The selection of the other parameters to be monitored depends upon specific requirements related to the type of nonpoint-source category and the media being sampled.

The instability of some parameters dictates that they be measured in the field, while others must be measured in the laboratory because of the complex analytical procedures required for sensitive determination.

Table 2 (Parameter Matrix) is organized into two parts. The first part consists of the parameters which may be measured *in situ*, and the second part lists those parameters that are usually measured in the laboratory. Included are indications of the relative importance of each parameter as associated with the five general categories of nonpoint-source pollution expressed in the first two parts of this report.

Table 2. PARAMETER MATRIX

	Agriculture	Silviculture	Mining	Construction	Hydrographic Modification
Field Measured Parameters					
Turbidity	P	P	P	P	P
Temperature	P	P	P	P	P
Specific ions	P	P	P	P	P
Specific conductance	P	S	P	S	S
pH	P	P	P	S	N
Oil and grease	N	N	P	P	N
Flow Rate	P	P	P	P	P
Dissolved oxygen	P	P	P	P	P
Laboratory Measured Parameters					
Acidity	S	S	S	S	S
Alkalinity	P	S	P	S	S
Chemical oxygen demand	P	P	P	S	S
Total organic carbon	P	P	S	S	S
Specific ions	P	P	P	P	P
Heavy metals	S	S	P	N	N
Suspended solids	P	P	P	P	P
Total dissolved solids	P	P	P	P	P
Nitrate	P	S	S	S	S
Nitrite	P	S	S	S	S
Nitrogen, Kjeldahl	P	S	S	S	S
Nitrogen, ammonia	P	S	S	S	S
Total nitrogen	P	S	S	S	S
Organic phosphorus	P	P	S	S	S
Total phosphorus	P	S	S	S	S
Chlorinated hydrocarbons	P	P	N	N	N
Organophosphates	P	P	N	N	N
Carbamates	P	P	N	N	N

P = Major component
S = Secondary component
N = Minor significance

Field Measurements With Contact Sensors

For some monitoring situations, automated sensors may be utilized to continuously measure and record selected parameters. The contact sensing devices used for making parametric measurements in water are either electro-chemical or electro-mechanical in nature. A specific parameter of water interacts stoichiometrically with the sensor to generate an analog voltage or current that is predictable and reproducible.

The sensors can be placed physically at the exact point in the stream where the measurements are desired; the signal processing electronics can be separated from the sensors and located ashore, or the water can be piped from the sampling point to the sensor location, thus having the sensors closer to the signal processing electronics. Pumping the water may change some parameters; however, the pumping method allows an integrated sample of the stream to be measured with one set of sensors.

Electronic contact sensors for water quality evaluation and trend monitoring make possible an automated sampling station with continuous recording of *in situ* data. This same system permits the data to be telemetered at predetermined finite intervals to any central point.

It is possible to build a monitoring system for suitable parameters that, if undisturbed, will maintain its calibration accuracy and repeatability for approximately 1 month, unattended.

Certain key parameters providing an overall indication of water quality can be measured automatically and continuously without regard to expected pollutants in an area. Significant changes in such parameters provide an alert for closer examination and more detailed sampling.

The following summary discusses those parameters which are suitable for monitoring with automated contact sensors.

Turbidity -

Turbidity is an expression of the optical property of water to scatter and absorb light rather than transmit it in straight lines through the sample. Some electronic turbidity sensors measure the amount of light deflected to the side of the incident light beam (nephelometer), while other sensors measure the percentage of light transmission on a fixed path length through the water sample (transmissometer) and extrapolate turbidity data; however, this is not a true measurement of turbidity.

The unit used for measurement of turbidity is the Jackson Turbidity Unit or JTU. Zero JTU denotes perfectly clear water; 1,000 JTU approaches the upper limit of turbidity. The larger number (JTU) indicates more light is deflected and absorbed by the suspended particles and colored substances in the water.

Since the electronic turbidity sensor is an optical device, any deposits or algal fouling on the optical windows will give erroneous results. The sensor should be oriented so that the stream flow accomplishes a natural flushing action for the optics. In highly enriched environments, the windows will still require frequent cleaning.

Temperature -

The four basic types of electronic sensors used for measuring temperature are thermocouples, resistance thermometers, thermistors, and semiconductor devices. The thermocouple develops an electrical potential across a junction of two dissimilar metals that varies directly with temperatures. The resistance thermometer is a coil of metal wire, usually platinum or nickel, whose resistance varies directly with temperature. Thermistors are non-metallic beads or discs whose resistance varies inversely with temperature. Semiconductor temperature sensors are usually silicon diodes whose nominal forward voltage drop is 600 mv. This voltage varies inversely with temperature. Each of these types of transducers requires analog circuitry to convert the sensor output to a direct-reading voltage analog.

Resistance thermometers are the most precise and some are quite linear over a broad temperature range; however, they are the most expensive to construct. Thermistors are linear over a narrower range and tend to drift slightly; they are the least expensive type. Semiconductor elements are quite linear over a broad temperature range, and are relatively inexpensive and stable. Sensors with narrow linear ranges require complex linearization circuits when

operated outside of that range. The calibrated accuracy of the temperature sensor should be ±0.1° C throughout the range of 0° C to 40° C; its time constant should not exceed 1 minute; and it should retain the calibration accuracy for greater than 4 weeks.

Specific Ions -

Sensors are available to measure over 20 different specific ions. At this time, only a few have proven reliable in an unattended field environment. These include the chloride and the fluoride sensors and the divalent calcium/magnesium or hardness sensor. The chloride sensor, however, has limited utility in fresh water as reproducibility is poor in solutions of low chloride concentrations or low ionic strength.

The units of measurement for specific ion sensors are decimal molar concentration or milligrams per liter. Specific ion sensors require temperature compensation.

Specific Conductance -

Conductance is a relative measure of ionic strength of the sample; it is the inverse of the electrical resistance. In a fresh water environment the unit of measure is micromhos per centimeter. Conductivity of water varies with temperature; when corrected to a standard 25° C, this value is termed Specific Conductance.

Conductance sensors are basically of two types. The first has conducting electrodes that are exposed directly to the water. An electrical potential is applied either directly to the measuring electrodes or to two other electrodes. The current in the sample is directly proportional to the conductivity. Another technique is to apply an alternating potential to the electrodes to reduce the galvanic effects and reduce electrode oxidation. This type of sensor requires regular cleaning to remove chemical and biological deposits that may mask some of the electrode surface.

The second type of sensor is inductive in nature; two toroidal coils are immersed in the sample, one of which is driven with an alternating current. This signal is inductively coupled to the second toroid by the conductivity of a water column that passes through both coils. The geometrical arrangement of the coils and the size of the water column are critical in the design of the type of sensor; the associated circuitry is more complex than the

exposed electrode approach. However, problems of deposits on the electrode are almost completely eliminated. The inductive sensor has been used most commonly in the marine environment where corrosion is an extreme problem. The National Eutrophication Survey of the EPA has used it quite successfully in fresh water.

pH -

By definition, pH is the negative logarithm of the hydrogen ion concentration. The practical sensor for measuring pH is an electrode made of a special pH sensitive glass. The electrode is used in conjunction with a reference electrode. They are available either together, in the form of a single combination electrode, or separately. Most combination electrodes and reference electrodes are pressure sensitive. However, some companies are now manufacturing pressure compensated combination electrodes and pressure compensation flowing junction reference electrodes. The Lazaran Process reference electrode is specified to operate to a pressure of 150 pounds per square inch, requiring no electrolyte seepage and no refilling. When this electrode is used in conjuction with a process glass pH electrode, the pair may be continuously submerged. The only maintenance required is periodic cleaning.

The electrodes generate an analog voltage proportional to the pH of the sample. The voltage is positive for acidic and negative for alkaline samples. The pH sensor requires a very high input impedance amplifier because of its own high internal impedance. The sensor is temperature sensitive and must be temperature compensated.

Oil and Grease -

Obtaining quantitative and qualitative data on oil and grease requires laboratory analysis. Sensors now being developed can electronically detect the presence of an oil film on the water surface. This indication is important as an alarm mechanism.

Dissolved Oxygen -

Most dissolved oxygen sensors used in water quality studies use a gas permeable membrane to measure the partial pressure of the oxygen in the water. The oxygen passes through the membrane at a rate directly proportional to the oxygen concentration or partial pressure and inversely proportional to the temperature of the membrane and water. The inside of the sensor contains a silver and gold electrode in a potassium chloride solution. The oxygen is electrochemically reduced inside the sensor by a polarizing potential applied to the silver electrode. The current passing through the sensor is directly proportional to the rate of oxygen being reduced and thus to the oxygen in the water. This current is converted to an analog voltage and temperature corrected to give a dissolved oxygen (D.O.) measurement. Since oxygen is being consumed continuously from the water, a flow of water past the sensor is required to keep the flow rate through the membrane in equilibrium with the D.O. in the sample. If the natural flow rate is insufficient to accomplish this, some form of mechanical stirrer must be used with the sensor. As the membrane fouls or deteriorates, it must be cleaned or replaced to prevent calibration shift. Process oxygen sensors are available which retain their calibration for longer than 4 weeks, if undisturbed.

Field Sample Collection

Sample Volume -

In selecting sample volume, several factors require evaluation: (1) the objectives of the sampling, (2) the type of collecting device, (3) the concentration of pollutant in the water, (4) the analysis or analyses to be performed on the sample, (5) the time available for sampling in the case of composite samples, and (6) minimum volumes necessary for quality control procedures and replicate measurements that may be desirable.

Some analytical procedures require that chemical preservatives be added to the sample rendering it unfit for other chemical analyses; consequently, it is sometimes necessary to collect multiple samples.

Sample Types -

There are three basic sample types:

(1) Grab Sample: A grab sample is usually a manually collected single portion of water. Analyses of properly handled grab samples measure characteristics of the water at the time the sample was collected.

(2) Continuous Sample: When points are to be sampled at frequent intervals or when a continuous record at the sampling station is required, an automatic or continuous sampler may be employed.

(3) Composite Sample: A composite is prepared by mixing together two or more individual samples. A volume-integrated composite is prepared by combining individual portions whose volume is proportional to the flow rate of the stream sampled. This results in a variable volume for the composite obtained over a fixed time period.

A time composite is a mixture of constant volume portions taken at specified time intervals. The composite can be both flow integrated and time composited, i.e., several portions are taken at equal time intervals with the volume depending on the flow rate at the sample time. These composites can be prepared manually or with automatic sampling devices.

Continuous samples are usually the most representative, but composite samples are acceptable for many purposes. Although a grab sample reflects the water quality at an instant in time, it is quite acceptable if judgment and discretion are exercised in its use.

Sampling Procedures and Equipment -

Specific recommendations for sampling procedures and equipment for the collection of water quality data are described in a preliminary report of the Federal Interagency Work Group on Designation of Standards for Water Data Acquisition (USDI, 1972) and in EPA publications (EPA, 1973 j).

Selection of sampling equipment will depend on the parameters to be collected. Stream conditions, the physical state of the pollutant, and physical limitations at the sample site will dictate the specific equipment most appropriate for collecting a representative water quality sample.

Sample Preservation -

An extremely significant aspect of the collection procedure is sample preservation. The physical, chemical, and biological characteristics of the sample will change with time, temperature, and exposure to light. Therefore, it is necessary, in many instances, to chemically treat samples to retard bacterial growth; refrigerate samples to reduce chemical and biological activity; and store samples in light-proof containers to inhibit photochemical reactions. Samples may require one or more of these preservation techniques to maintain the original characteristics of the sample. No presently available preservation techniques are universally suitable for all likely parameters; *in situ* analysis is often still necessary.

Sample Identification -

An important factor in sampling is the accurate and complete identification of each sample. A unique sample identification code should be used for each station. The use of tags upon which identifying data may be entered is satisfactory provided the tags are moisture resistant and do not become soiled or damaged during use.

Quality Assurance -

Because of the importance of analytical analyses and the resulting actions which they produce, a program to assure the reliability of the data is essential. It is recognized that all analysts practice quality control to varying degrees, depending somewhat upon their training, professional pride, and awareness of the importance of the work they are doing. However, under the pressure of daily workload, analytical quality control may be easily neglected. An established routine control program applied to every analytical test is important in assuring the reliability of the final results.

The goal of the quality assurance program is to produce accurate and reliable data. In establishing a program it is important to consider the following:

(1) Documentation of monitoring system design.

(2) Standardization of sampling techniques and equipment.

(3) Standardization of analytical procedures.

(4) Establishing a duplicate sampling and analysis program.

(5) Participation in interlaboratory cross-check programs.

(6) Standardization of reporting and feedback information systems for users.

(7) Standardization of electronic sensors used for *in situ* monitoring.

For detailed procedures on laboratory quality control, consult the *Handbook for Analytical Quality Control in Water and Wastewater Laboratories* (EPA, 1972). These methods and techniques have been adopted by EPA laboratories and provide a common base for data between Agency programs.

Sample Control -

Samples sent from the field to the laboratory should be routed through a sample control system. The sample should be logged in and all information pertaining to sample collection should be recorded on an appropriate sample control form. Each sample should be assigned a unique laboratory identification number with parameter analysis and routing identified. The data analysis system should have the provision to keep track of all samples as they proceed through the required analytical procedures; this insures against sample loss or incomplete sample analysis.

Laboratory Analytical Procedures

Physical, chemical, and microbiological analyses in stream measurements are specified in regulations published in 40 CFR, Part 35, Appendix A (Quarles, 1974), which includes selected methods from Standard Methods for the Examination of Water and Wastewater (APHA, 1971), Annual Book of Standards, Part 23, Water; Atmospheric Analysis (ASTM, 1973) and Methods for Chemical Analyses of Water and Wastes (EPA, 1971). These methods are required to be used by the States in primary monitoring network sample analyses.

Remote Sensing

Remote sensing techniques, such as infrared thermal mapping, multispectral scanning and satellite imagery, emerged as valuable aids in assessing the need for, and effectiveness of, nonpoint pollution control programs. Infrared aerial photographic and mapping reconnaissance surveys provide a rapid means of identifying sources and potential sources of pollution and delineating areas of high sediment loads in major water bodies. It is frequently possible to relate land-use practices and landscape characteristics to sediment loads in waterways utilizing such techniques.

The verification of mining, construction, and farming land-use practices can be accomplished in a cost-effective manner by use of high resolution aerial photography. These services are now available commercially. Both the EPA and the National Aeronautics and Space Administration (NASA) have developed techniques for identifying land-use practices from photographs, and NASA has published two handbooks on the use of small-scale photography for land-use mapping (NASA, 1972 a) and classification (NASA, 1972 b). These handbooks were designed to provide simple procedures by which large land areas can be economically categorized. These studies have shown the utility of such techniques applied to forestry, hydrology, agriculture, and mining. The reports provide procedures particularly useful to agencies or planning groups in need of land-use information, and operating with limited resources of personnel and funding.

Remote sensors which may be suitable for measuring relative river centerline suspended sediment and salinity concentrations are in the planning stage. These instruments would be of tremendous assistance in locating nonpoint pollution sources for purposes of designing ground-based monitoring networks and surveillance systems. It may also be possible to utilize a combination of ground-based and airborne sensors to determine suspended sediment and salinity dispersion patterns. Relationships could be established by preparation and verification of models.

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